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CHARACTERISATION OF UNSTEADY FLOWS IN CENTRIFUGAL IMPELLERS

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SUMMARY

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Nomenclature

C	Absolute velocity
N	Number of revolutions
P	Pressure surface
R	Radius
S	Suction surface
t	Time

U Impeller tip speed

W Relative velocity

α Absolute flow angle

ω Angular velocity

θ Angular location of flow from pressure surface

ϕ Flow coefficient

Subscripts

a Actual

av Average

m Measured

2 Impeller outlet

3 Location of hotwire sensor

Superscripts

' Location of the flow from pressure surface after time t

Introduction

Flow through a centrifugal compressor impeller is three dimensional in nature skewed by secondary flows generated within the vaned passages(Reference-1). Quite often the flow is assumed to be steady with property variations across the blade-to-blade as well as hub to shroud channel(Reference-2). Quasi three dimensional potential flow theory or empirical modelling such as jet wake flow are then used to analyse the flow within the channel and to compute outlet conditions(Reference-3). Unsteadiness, if any, are considered only as large scale turbulence of random nature particularly in the wake region. Measurements using hot wire anemometry in the present investigation indicate a periodic phenomenon of unsteadiness with spectral variations. This paper describes a technique developed for an appropriate analysis of hot wire measurements and the resulting characteristic of unsteady flow phenomenon at impeller outlet.

Test Facility and Instrumentation

A centrifugal impeller of 525 mm diameter, 45.5 mm width with 23 vanes backswept by 40 degrees with reference to radial direction rotated at 5000 RPM by a DC motor. Thyristor control with feedback for the DC motor ensured maintenance of the speed to an accuracy of 0.1%. The massflow rate through the impeller

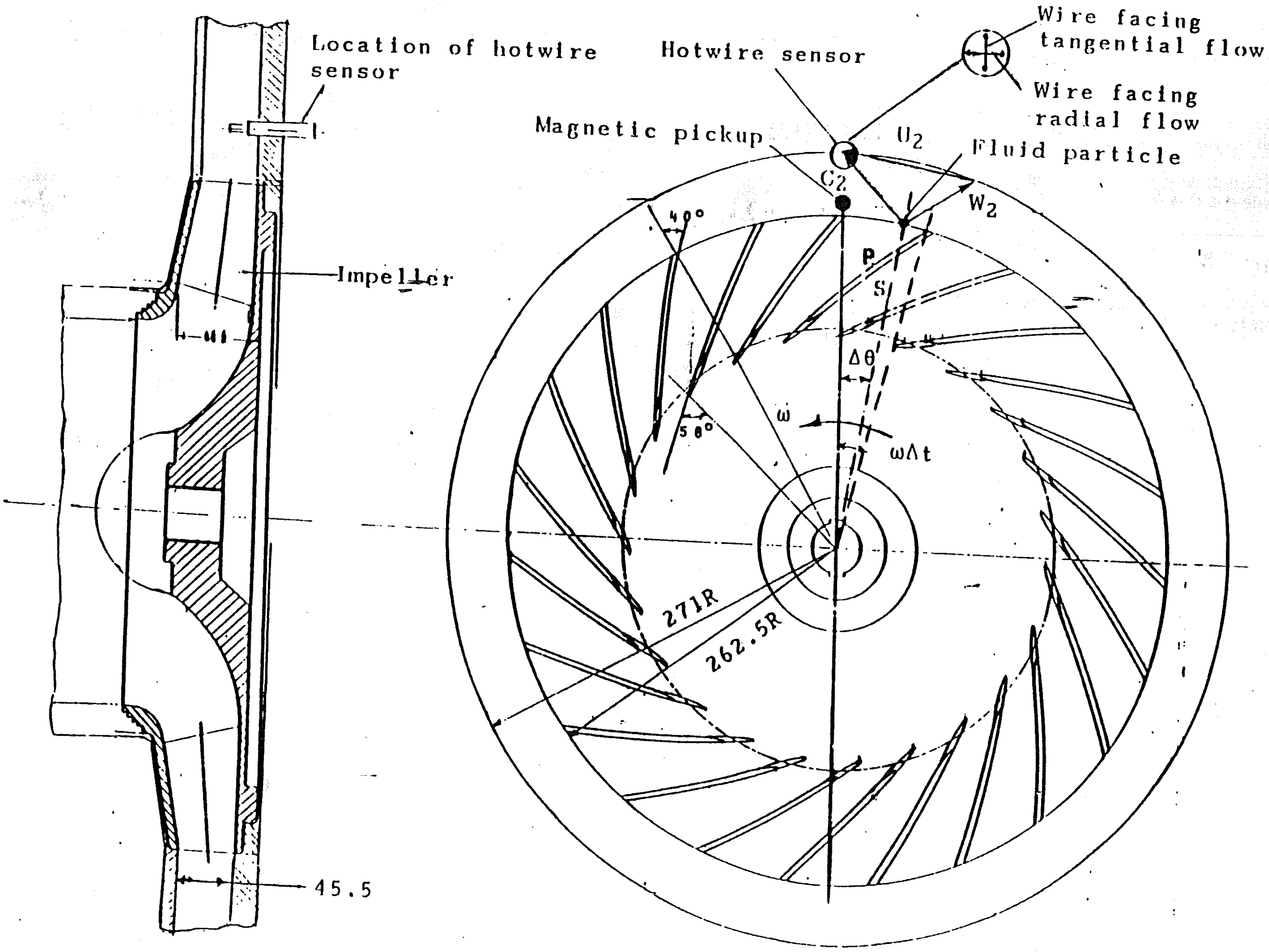

Figure-1. Geometrical Details of Centrifugal Impeller was varied by a special throttle arrangement provided at volute outlet. A hot wire anemometer placed 8 mm radially outwards of the impeller as shown in Figure-1 was used in two angular positions to measure radial and whirl components of velocity in a dynamic mode across the blade-to-blade pitch at the mid channel, hub to shroud width of the impeller at outlet. A linearizer was used in conjunction with the hot wire anemometry circuit and calibration was carried out separately in a steady uniform flow before and after the experiment. The traces were captured through a computer controlled dual beam signal analyser (FFT analyser) and recorded through its memory onto magnetic discs. An once per revolution spike generated from a magnetic pick up and shaft projection was used to trigger the hot wire trace and record the same for a duration of 50 milli seconds corresponding to nearly 4 revolutions. 50 Such recordings one after the other in a phase locked manner could be obtained to get the ensemble average of signal across 92 blade passages. The blade passing frequency is about 1.92 Khz.

Results and Discussion

Voltage signals proportional to flow velocity were obtained with two orientations of the hot wire perpendicular to each other, thus providing the radial and whirl components separately. The axial component was negligible owing to the probe location being in the mid channel width. From these measurements the total absolute velocity and flow angle could be computed. Measurement by this method provides velocity variations with respect to time as picked up by the probe at the point where it is located. Continuous recording over 50 milli seconds has been made to cover 92 passages in a phase locked manner to ensure channel and velocity correspondence. At an impeller speed of 5000 RPM one blade pitch takes 12/23 milli seconds and the computed absolute velocity was plotted one over the other for a periodic pitch of 12/23 milli seconds. Such a plot in full line

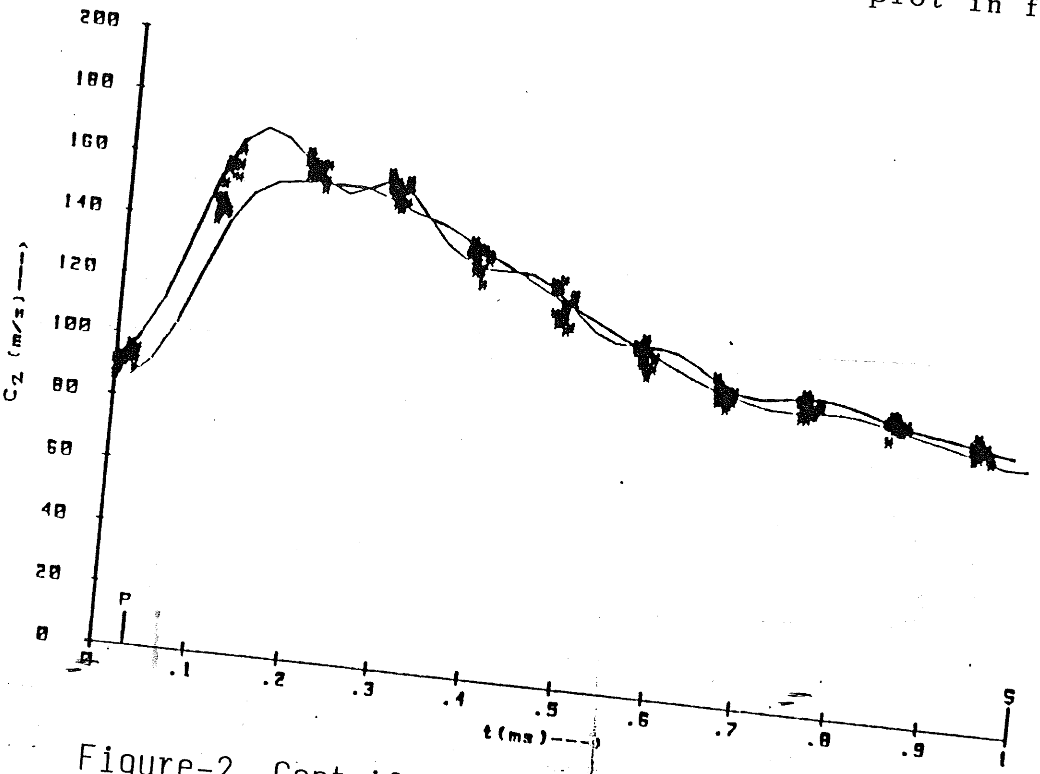

Figure-2. Centrifugal Impeller Outlet Flow

is shown in Figure-2 with pitchwise variations for only two passages shown for clarity. It is readily seen that apart from the pitchwise variation of velocity from suction surface to pressure surface of the passage, there is a timewise variation also as the two distinctly different traces reveal. In the absence of a rotating stall symmetry of flow from passage to passage can be assumed. This is confirmed by subsequent analysis as below which indicates steadiness only in a narrow region within the blade passage.

The velocity measured by the hot wire at any given instant of time actually corresponds to an absolute flow leaving impeller tip at the flow angle. Generally, when the flow i steady, timewise capture of velocity can be considered equivalent to variations with respect to relative angular position given by ωt. Since the probe is located at a finite distance of 8 mm radially outwards from impeller tip and the absolute flow direction is not being radial, the actual point from where the flow left the impeller to reach the probe will have an angular shift $\Delta\theta$ from probe radial line and also the measured velocity will correspond to the velocity on impeller point at a time earlier than the recorded instant time by an amount Δt. In an unsteady flow the relative angular position whose velocity was captured would change due to the above two factors by an amount ($\Delta\theta - \omega\Delta$). These shifts in angular position and time can be computed by assuming momentum conservation in the absolute flow field outside the impeller. The actual velocity with which flow left the impeller will also be calculated by correcting for the small amount of variation in radial locations of impeller point and probe.

$$\Delta\theta = \tan\alpha_2 \cdot \log R_3/R_2$$

$$\Delta t = (R_3 - R_2)(R_3 + R_2)/2R_2CR_2$$

$$Ca = Cm\ R_2/R_3$$

$$\theta' = \omega t + \Delta\theta - \omega\Delta t$$

$$= \tan\alpha_2 \cdot \log R_3/R_2 - \omega(\Delta t - t)$$

The velocity signal measured by the hot wire with respect to time could now be converted to velocity variations with respect to relative angular position measured from the pressure surface and plotted for a given blade-to-blade pitch. The corresponding

/o such plots are shown in Figure-3. The difference between

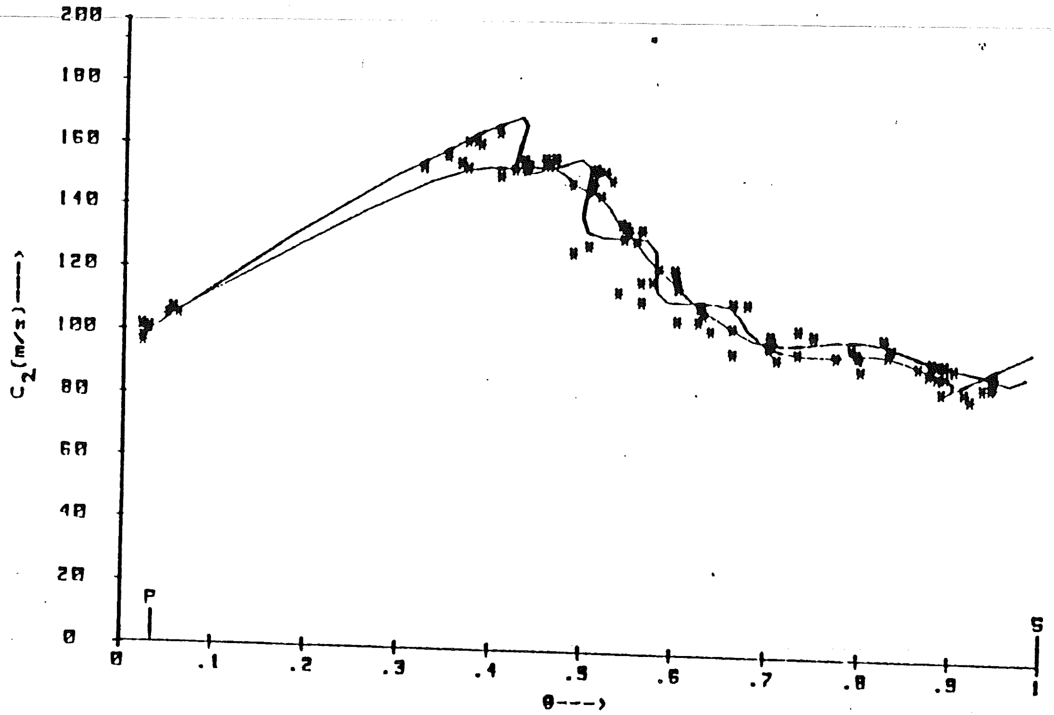

Figure-3. Centrifugal Impeller Outlet Flow

time wise plot and position wise plot is strikingly clear. The flow is so unsteady that the flow at a given position is picked up more than once within a single sweep of the passage. The flow at these points having a vortex motion of changing angular direction with respect to time could be inferred from this observation.

Having obtained velocity measurements plotted against angular position at impeller outlet, the variation of velocity at a given location with time could be derived assuming symmetry of flow field in each passage. From each of the 92 passage sweeps for a given location one or more than one velocity measurement and the corresponding time when it occurred could be got and plotted as velocity variation with time at that chosen location. Such exercises carried out for six different angular positions in a blade passage are shown in Figure-4. It is quite interesting

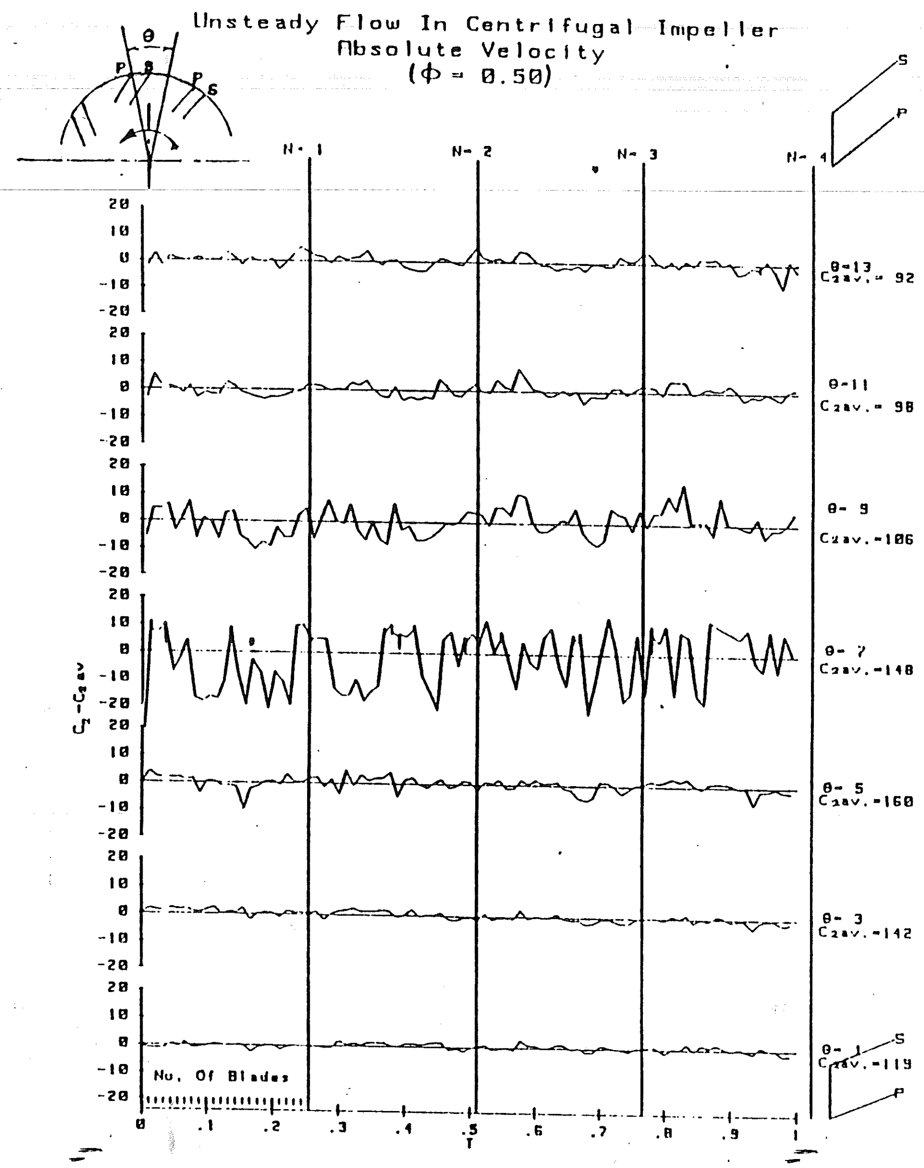

Figure-4.

to note that large unsteadiness of flow with distinct periodicity is observed only at 7 deg. and 9 deg. points away from the suction surface of the impeller for this flow coefficient. Elsewhere the flow is very steady without any variation in velocity with time. The periodicity of unsteadiness observed at certain points do not correspond to blade passing frequency nor the rotational frequency. This would lead to the inference that the flow within the passage is disturbed by secondary vortices shed within the passage into the flow at periodic intervals of approximately three times in each revolution. Thus the aracteristic of unsteadiness in the flow far from being a random turbulence, exhibits a periodic nature with a spectral frequency of three times the rotational speed.

Conclusions

The measurements indicate that there is pitchwise (spacial) and timewise (temporal) variation of velocity from suction surface to pressure surface of the passage at impeller outlet. There is a difference in velocity distribution between time wise plot and position wise plot. The position wise plot of velocity indicates that the flow is highly unsteady, since the flow at a given location is picked up more than once within a single sweep of the passage. The flow at these points has a vortex motion of changing angular direction with respect to time. The variation of velocity at a given angular location with respect to time indicates that flow within the passage is disturbed by secondary vortices shed within the passage into the flow at periodic intervals of approximately three times in each revolution.

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